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MISSILE VULNERABILITY (MV)
CODE SIMPLIFICATION

Michael O. Schick

January 1977

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I. INTRODUCTION

A simplification to the missile vulnerability code (MV)¹ has been derived which takes into account the linear nature of existing missile trajectory data. This simplification allows for approximately a fourfold decrease in the number of parameters required to describe missile vulnerability data. The major use of MV data is in wargaming programs where computation time and storage space are generally quite limited. Thus, a reduction in the number of descriptive parameters will benefit wargamers using the data.

II. DISCUSSION

The MV code simplification is based on two assumptions. The first assumption is that the laser vulnerability (LV) code generated P_D (probability of damage) data may be parameterized by a "slanted Step" function.² That is, the missile P_D as a function of laser dwell time t may be represented as:

$$\begin{aligned} P_D &= 0 & t_{th} > t \\ P_D &= P_{D\text{MAX}} \left(\frac{t - t_{th}}{t_{\text{max}} - t_{th}} \right) & t_{th} \leq t < t_{\text{max}} \\ P_D &= P_{D\text{MAX}} & t_{\text{max}} \leq t \end{aligned} \quad [1]$$

where t_{th} = threshold dwell time

$P_{D\text{MAX}}$ = maximum P_D achievable

t_{max} = maximum effective dwell time

The second assumption is that the missile trajectory data may be represented by a linear function of miss distance versus initial damage range. Thus we have

$$x = mR + b \quad [2]$$

where x = miss distance

R = initial damage range,

¹ M.O. Schick, "Missile Vulnerability (MV) Code User's Manual," Ballistic Research Laboratory Report No. 1924. (AD #B013530L)

² J.T. Klopce, "A Proposed Laser Vulnerability-Wargaming Interface", Ballistic Research Laboratory Memorandum Report No. 2533 (AD#B0074286)

and m, b are constants determined by fits to missile trajectory data, where damage has been initiated at various points along the trajectory. The above formula accurately describes missile trajectory data obtained to date.

The relevant output of a missile vulnerability analysis is the differential probability of impact as a function of miss distance, dP_I/dx . For the damaged missile there is a one-to-one correspondence between the damage probability, P_D , and the impact probability P_I . That is, an incremental change in the missile P_D implies an equal change in the impact probability P_I , or $dP_I/dP_D = 1$. Using this simple relationship, the relevant quantity dP_I/dx may be derived from Equations 1 and 2. From Equation 1 we have, for $t_{th} \leq t < t_{max}$,

$$\frac{dP_I}{dt} = \frac{P_{D\text{MAX}}}{t_{\text{max}} - t_{\text{th}}} \quad . \quad [3]$$

From Equation 2 we have

$$\frac{dx}{dR} = m \quad . \quad [4]$$

Then, combining Equations 3 and 4, we get

$$\frac{dP_I}{dx} = \frac{dP_I/dt}{dx/dR} * \frac{1}{dR/dt} = \frac{P_{D\text{MAX}}}{(t_{\text{max}} - t_{\text{th}})m} \frac{1}{V} \quad [5]$$

where $V = dR/dt$ is the missile velocity. Now for most situations, the missile velocity may be assumed constant over the time interval from t_{th} to t_{max} . Thus, we see, from Equation 5, that dP_I/dx is constant over this time interval. A plot of dP_I/dx versus x would yield a flat distribution with limits defined by the values of x corresponding to values of R at the times t_{th} and t_{max} . These values of x are simply

$$x_{\text{min}} = mR_{\text{min}} + b \quad [6a]$$

$$x_{\text{max}} = mR_{\text{max}} + b \quad [6b]$$

where

$$R_{\text{min}} = R_{\text{initial}} - v * t_{\text{max}} \quad [7a]$$

$$R_{\text{max}} = R_{\text{initial}} - v * t_{\text{th}} \quad [7b]$$

Here R_{initial} is the initial range, R_{max} is the range at which the P_D begins to accumulate, and R_{min} is the range at which P_{Dmax} has accumulated.

It is assumed that the dP_I/dx distribution cuts off sharply at the limits X_{min} and X_{max} . Realistically, we expect the distribution to fall off more gradually at the end points. The miss distance as calculated from Equation 2 is not completely deterministic, and actual miss distances would be distributed about the calculated value. In reference 1 a Gaussian distribution about the calculated miss distance was assumed, and the accumulated probability of kill was distributed over a range of miss distances.* Here we ignore the tails of the distribution in order to simplify the results. The error made in doing this is negligible, as will be shown in the next section.

III. EXAMPLE

A sample calculation is performed to illustrate the simplicity of the derived methodology. Let us assume that the missile velocity is 260 metres/second and the missile CEP (circular error probable) is 7.6 metres. Assume the miss distance equation is given by

$$X = .25R - 100 \quad [8]$$

The following quantities define the missile P_D (see Equation 1):

$$\begin{aligned} t_{\text{th}} &= .2 \text{ sec} \\ t_{\text{max}} &= 2.2 \text{ sec} \\ P_{\text{Dmax}} &= .9 \end{aligned}$$

We first calculate the miss distance distribution for a dwell time of 1 second. From Equation 5 we have

$$\frac{dP_I}{dx} = \frac{(.9)}{(2) \cdot .25} \cdot \frac{1}{260} = .0069 \text{ /metre} \quad [9]$$

From Equation 7 we calculate

$$\begin{aligned} R_{\text{max}} &= 1000 - 260 \cdot .2 \\ &= 948. \text{ metres} \end{aligned} \quad [10]$$

$$\begin{aligned} R_{\text{min}} &= 1000 - 260 \cdot 1. \\ &= 740 \text{ metres} \end{aligned} \quad [11]$$

* See Appendix B in Reference 1

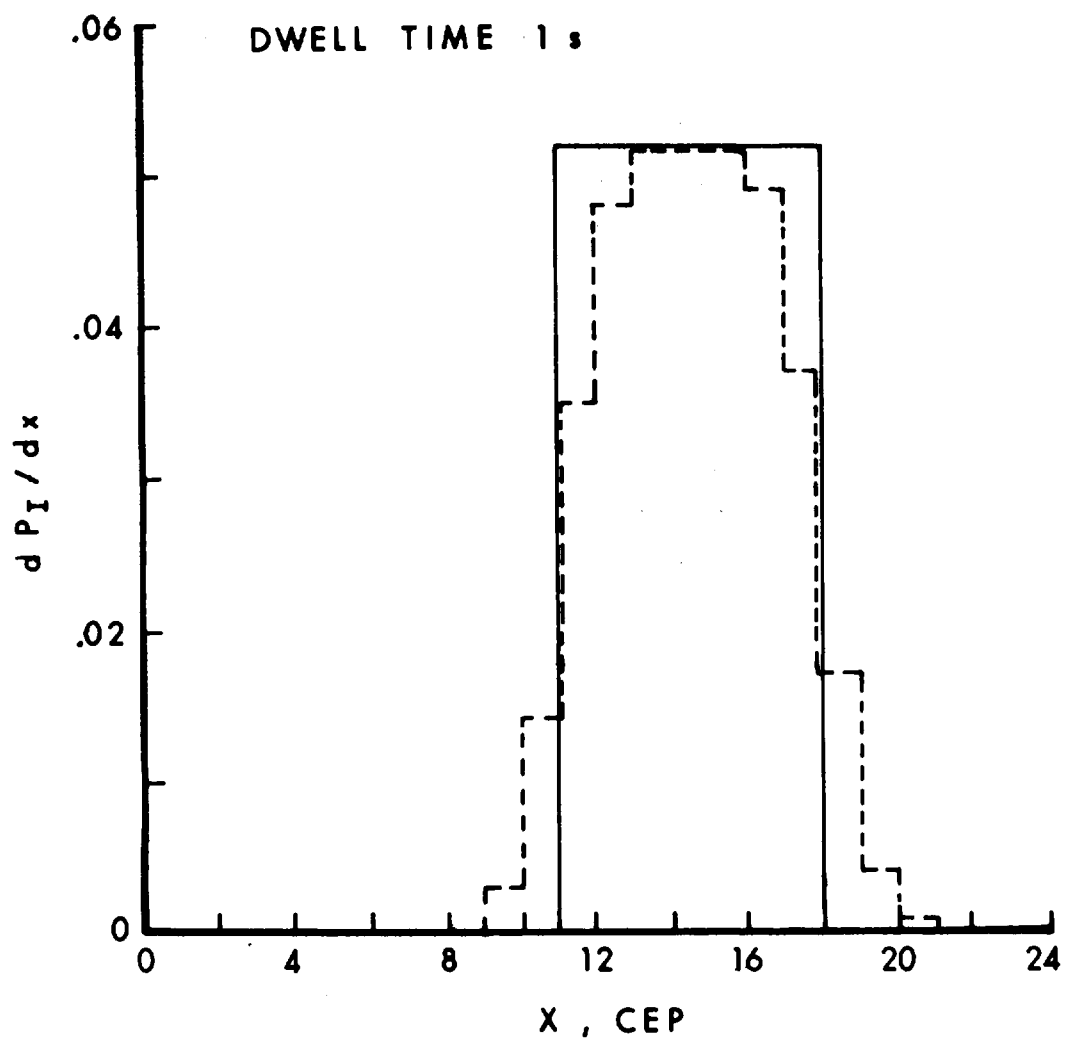


Figure 1. Damaged Missile Impact Distribution

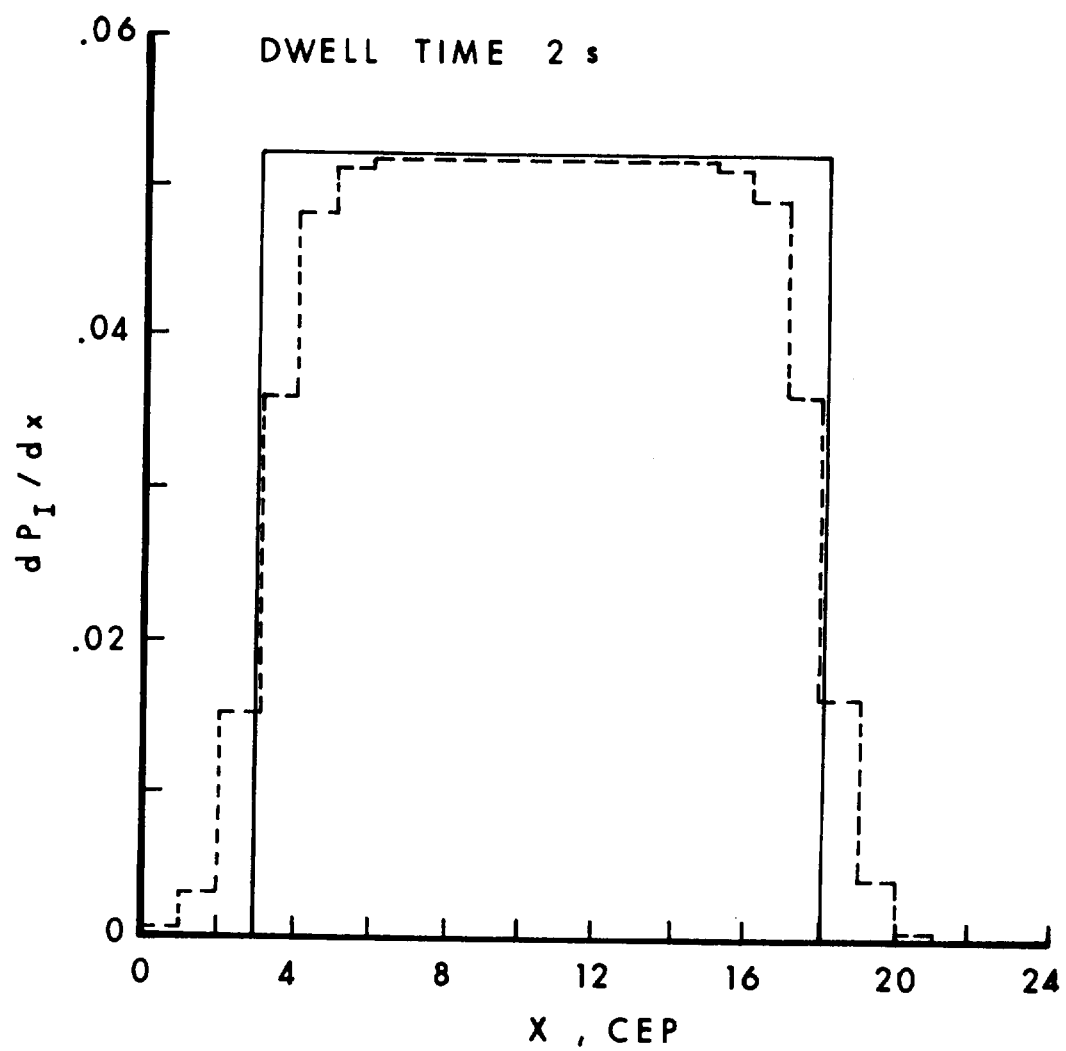


Figure 2. Damaged Missile Impact Distribution

Thus, from Equation 8, we have

$$\begin{aligned} X_{\max} &= .25(948.) - 100 \\ &= 137. \text{ metres} \end{aligned} \quad [12]$$

$$\begin{aligned} X_{\min} &= .25(740.) - 100 \\ &= 85. \text{ metres} \end{aligned} \quad [13]$$

The distribution will be plotted in CEP intervals. Converting Equations 9, 12 and 13 to CEP units, we get

$$\frac{dP_I}{dx} = (.0069)(7.6) = .052/\text{CEP} \quad [14]$$

$$X_{\max} = 137./7.6 \sim 18 \text{ CEP} \quad [15]$$

$$X_{\min} = 85./7.6 \sim 11 \text{ CEP} \quad [16]$$

We note that 3 quantities, dP_I/dx , X_{\max} , and X_{\min} are sufficient to describe the distribution. By contrast, the original formulation of the problem required that dP_I/dx be specified for each CEP interval. Thus to specify the distribution out to 10 CEP from the origin required 10 numbers, and information about the distribution beyond 10 CEP was lost. The distribution is plotted in Figure 1 as a solid line. Also shown in Figure 1 is the same distribution with the effects of dispersion included (dashed line). It can be seen that the tails of the distribution are small and can be neglected. The same calculation will now be performed for a 2 second dwell time. We note that the calculations of dP_I/dx and X_{\max} are the same as before. To calculate X_{\min} we have

$$\begin{aligned} R_{\min} &= 1000 - 260 * 2. \\ &= 480. \text{ metres} \end{aligned} \quad [17]$$

and thus

$$\begin{aligned} X_{\min} &= .25(480.) - 100 \\ &= 20 \text{ metres} \\ &= \frac{20}{7.6} \sim 3 \text{ CEP} \end{aligned} \quad [18]$$

The distribution is plotted in Figure 2 (solid line), and again we note that the tails of the dispersed distribution (dashed line) are negligible. Thus far we have been concerned with the impact distribution for a damaged missile. The damaged missile impact probability P_I is obtained by integrating dP_I/dx over the miss distance X . In Figure 2, for instance, the integrated probability under the solid line equals 0.78. There are, however, two other sources of probability for a given engagement. One

is the probability of catastrophic kill, P_C , and the other is the survival probability P_S . The probability of catastrophic kill is the probability of defeating the missile before ground impact, i.e., a warhead kill, while the survival probability is defined as the probability of the missile completing its mission without being damaged. The sum of the three probabilities must be unity to conserve total probability:

$$P_I + P_C + P_S = 1 \quad [19]$$

The survival probability P_S is distributed according to the usual circular Gaussian distribution (see Reference 1). Let us assume for simplicity that the probability of catastrophic kill P_C equals zero. We then have

$$\begin{aligned} P_S &= 1 - P_I - P_C \\ &= 1 - .78 \\ &= .22 \end{aligned} \quad [20]$$

The survival probability is plotted in Figure 3 along with the impact distribution from Figure 2.

IV. SUMMARY

A simplification to the MV code has been derived for situations where the missile miss distance is a linear function of damage range. This simplification provides for a more concise representation of the data and is advantageous for wargaming applications. A sample Fortran program which will perform the calculations described in sections II and III is listed in the Appendix.

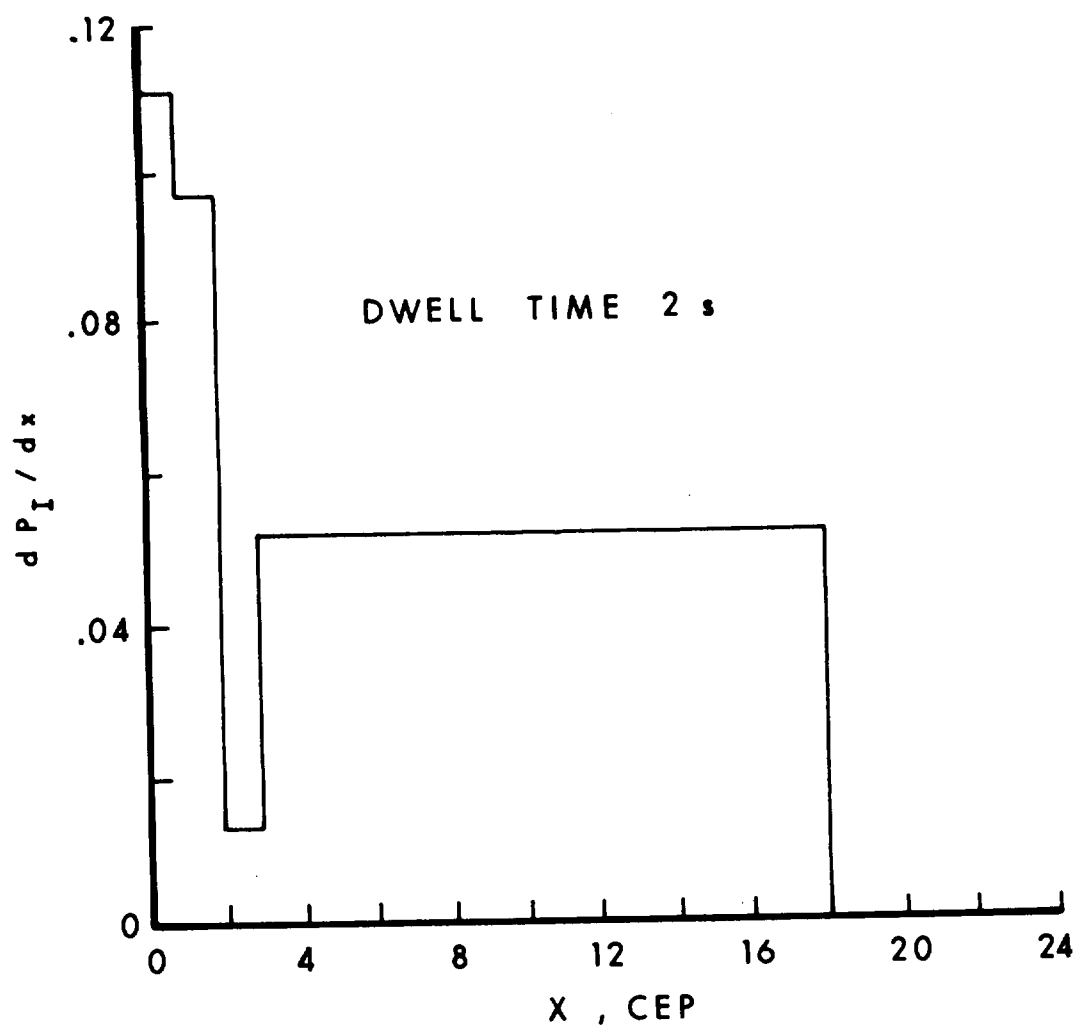


Figure 3. Missile Impact Distribution

REFERENCES

1. M.O. Schick, "Missile Vulnerability (MV) Code User's Manual," Ballistic Research Laboratory Report No. 1924. (AD #B013530L)
2. J.T. Klopckic, "A Proposed Laser Vulnerability-Wargaming Interface," Ballistic Research Laboratory Memorandum Report No. 2533 (AD#B0074286)

APPENDIX
Sample Fortran Program

*MSTEMP,MVFAS

```

1      C      THIS ROUTINE WILL CALCULATE THE IMPACT DISTRIBUTION FOR A
2      C      MISSILE. REQUIRED INPUTS ARE PARAMETRIZED LV DATA (SLANTED
3      C      STEP FUNCTION), THE MISSILE CEP AND VELOCITY, AND THE MISS
4      C      DISTANCE AS A FUNCTION OF RANGE. THE IMPACT DISTRIBUTION
5      C      IS PRESENTLY CALCULATED FOR RANGES OF 1,2,3,4, AND 5 KM,
6      C      AND FOR DWELL TIMES OF 1,2,3, AND 4 SEC. THE OUTPUT
7      C      VARIABLES ARE THE NEAREST (TO MISSILE TARGET) CEP INTERVAL
8      C      IMPACTED, THE FARTHEST CEP INTERVAL IMPACTED, AND THE TOTAL
9      C      PROBABILITY OF KILL, WHICH IS A FLAT DISTRIBUTION BETWEEN
10     C      THESE TWO POINTS.
11     C
12     C
13     C      DIMENSION XAP(3)
14     C      DATA CEP/7.6/VELOC/260./DMDR/.25/CON/-100./
15     C      INTEGER INF/10/OUTF/11/
16     C      DATA RMIN/400./
17     C
18     C
19     C      READ IN LV DATA ON FILE INF
20     75     READ(INF,100,ERR=1000,END=2000) ID,INSEQ,THETA,PHI,XAP,
21     $BRY,PKPWRT,SIGMA,T1,T2,P2,CHISO
22     100    FORMAT(A2,I4,2F4.0,3F5.1,F4.2,1PE8.2,0PF4.1,3X,3F5.2,1PE9.2)
23     C
24     C      INITIALIZE
25     C      ICEP1 = 0
26     C      ICEP2 = 0
27     C      PROBK = 0.0
28     C      IF(P2.LE.0.) GO TO 25
29     C
30     C      LOOP OVER INITIAL RANGE
31     C      DO 1 I = 5,1,-1
32     C      RANGI = FLOAT(I)*1000.
33     C      LOOP OVER DWELL TIME (TD)
34     C      DO 1 J = 1,4
35     C      TD = FLOAT(J)
36     C      IF(TD.LE.T1) GO TO 25
37     C      COMPUTE INITIAL DAMAGE RANGE
38     C      RI = RANGI - VELOC*T1
39     C      IS T2 GREATER THAN DWELL TIME
40     C      TFIN = T2
41     C      IF(T2.GT.TD) TFIN = TD
42     C      COMPUTE FINAL DAMAGE RANGE
43     C      RF = RANGI - VELOC*TFIN
44     C      COMPUTE ACCUMULATED PK
45     C      PROBK = (TFIN - T1)*P2/(T2-T1)
46     C      DETERMINE CEP INTERVAL LIMITS
47     C      IF(RI.LE.RMIN) GO TO 25
48     C      XMIS2 = DMDR*RI + CON
49     C      ICEP2 = XMIS2/CEP + .5
50     C      IF (RF.GT.RMIN) GO TO 10
51     C      SPECIAL CASE, DWELL TIME UP TO RMIN IS CALCULATED
52     C      ICEP1 = 1
53     C      TDD = (RANGI-RMIN)/VELOC
54     C      PROBK = (TDD-T1)*P2/(T2-T1)
55     C      GO TO 25
56     10     CONTINUE

```

```

57      XMIS2 = DMDR*RF + CON
58      ICEP1 = XMIS2/CEP + .5
59      25      CONTINUE
60      C      WRITE DATA FOR ONE RANGE, DWELL TIME
61      WRITE(OUTF,200,ERR=3000,END=4000) ID,INSEQ,THETA,PHI,RRY,
62      $PKPWRT,SIGMA,VELOC,RANGI,CEP,TD,ICEP1,ICEP2,PROBK
63      200      FORMAT(A2,I4,2F4.0,F4.1,1PE8.2,0PF4.1,F4.0,F5.0,F4.1,F2.0,
64      $2I3,F4.2)
65      1      CONTINUE
66      GO TO 75
67      C
68      C      ERROR EXITS
69      1000     WRITE(6,1001) INF
70      1001     FORMAT(' ERROR IN READING FILE',I5)
71      STOP
72      3000     WRITE(6,3001) OUTF
73      3001     FORMAT(' ERROR IN WRITING FILE',I5)
74      STOP
75      4000     WRITE(6,4001)
76      4001     FORMAT(' END OF FILE REACHED ON WRITE COMMAND')
77      STOP
78      C
79      C      NORMAL EXIT
80      2000     WRITE(6,2001)
81      2001     FORMAT(' JOB COMPLETED')
82      STOP
83      END

```

RT,S MSTEMP,MVFAS

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